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LEVEL II

HIGH SPEED SONAR ARRAY DEPRESSOR

PROGRAM FINAL REPORT

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This report describes a two year program directed towards the development of a high-speed, lightweight depressor for towing a sonar array from surface ships. The report covers the design, fabrication and model basin test of a half scale model and the design, fabrication, model basin test and at-sea test of a full scale demonstration model.

Results of the test program have verified the hydrodynamic performance and demonstrated the ease of handling a lightweight depressor. It is practical for a 265 pound (1180 N) depressor towing a sonar array at 26 knots to develop a depressing force of 7000 pounds (31,000 N).

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SUMMARY

This report describes a two-year program directed towards the development of a high-speed, lightweight depressor for towing a sonar array from surface ships. The report covers the design, fabrication and model basin test of a half scale model and the design, fabrication, model basin test and at-sea test of a full scale demonstration model.

Results of the test program have verified the hydrodynamic performance and demonstrated the ease of handling a lightweight depressor. It is practical for a 265 pound (1180 N) depressor towing a sonar array at 35 knots to develop a depressing force of 7000 pounds (31,000 N).

PREFACE

This report covers the work performed by the EDO Corporation in design, fabrication and test of a high speed towed sonar array depressor. The conceptual depressor design was performed with EDO internal funds while the full scale model development was funded by the Office of Naval Research (ONR) Code 220 and the Naval Underwater Sound Center in New London, Code 3232.

In September 1979, ONR issued Contract N0C014-79-C-0585 for EDO to fabricate and tank test a one-half scale depressor model that had been designed under an EDO funded Research and Development Program (PR&D). After the successful completion of the one-half scale model tank tests at the David W. Taylor Naval Ship Research and Development Center (DWTNSRDC), ONR modified Contract N00014-79-C-0585 to provide for the detail design of a full-scale depressor utilizing a Fathom Flexnose faired tow cable provided by MAR, Inc.

The objective of the ONR depressor program was to utilize the EDO depressor with a Gould towed array module and ATAP signal processor and to demonstrate at-sea that all of the components of a depressor tow system could play together.

Contracts N00014-80-C-0695 and N00014-80-C-0726 were issued in September 1980 to cover the depressor fabrication and both the model basin tests at DWTNSRDC and the sea-trials on the R/V ATHENA.

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1. INTRODUCTION

The EDO high speed depressor development program was initially directed towards use with future sonar systems and platforms. The original goals were:

1) Tow a low-self-noise sonar array at a depth of 500 feet (152 meters) at a speed of 45 knots.

2) Provide the capability of remotely varying the depressor depth without altering the tow cable scope.

3) Minimize the weight of the depressor system and associated handling equipment.

4) Include a feed-through array handling feature established under an EDO funded program ED 084.*

Under the ED 108** program, EDO defined a depressor that would meet these goals. The depressor would be capable of generating 11,500 pounds (51.2 kN) of depressing force at 45 knots to place a 3270 pound (145 kN) drag array at a depth of 500 feet (152 m) when towed by 750 feet (229 m) of 0.48 inch (12 mm) thick integrated, high strength, low drag tow cable (under development at DTNSRDC). The tow cable is not as yet fully developed, and must be further increased in strength to have an acceptable factor of safety at 45 knots. A half-scale model was designed and ultimately (under ONR funding) fabricated and successfully tested at DTNSRDC.

By the start of the half-scale model basin test, the emphasis of the program had been changed. Either the EDO design or a competing MAR, Inc. design was to be built to support a full-scale demonstration of a depressor tow system utilizing various system components funded by ONR. The demonstration was to be performed aboard the R/V ATHENA during the summer of 1981.

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*ED 084 - Dev. of Dynamic Dep. for a Ship Towed Sonar Array - Rpt. 11531

**ED 108 - High Speed Towed Array Depressor Program - Rpt. 11587

It was recognized that achieving the depth/speed goal of the depressor program was impossible during the R/V ATHENA demonstration. This was due to the low top speed of the ATHENA (35 knots maximum) and the high drag and low strength characteristics of the available faired tow cable.

In September of 1980, ONR funded EDO for the fabrication of the full-scale demonstration depressor and support of model basin testing at DTNSRDC and sea-trials on the R/V ATHENA.

The full-scale demonstration depressor was successfully tested at the model basin in June 1981. In July and August of 1981, the depressor was towed at a top speed of 34 knots by the Athena. A subsequent trial was performed with the same equipment installed on the JEFF A Landing Craft Air Cushion Vehicle. During this trial the depressor was towed at speeds in excess of 40 knots.

Except for the loss of some engineering data caused by instrumentation difficulties, the ONR depressor program succeeded in meeting its goals. Very low speed operation was hampered by a long, heavier-than-water, "stub" cable between the array and the depressor that was not anticipated in either the original depressor design nor the DTNSRDC basin test.

The trials demonstrated that the depressor is stable, remotely adjustable, capable of towing an array at speeds in excess of 40 knots and developing the depressing force necessary to meet the ultimate depth goal providing a suitably strong, low-drag tow cable is used.

2. TOW SYSTEM DESCRIPTION

The three major components of the demonstration depressor tow system are:

1) Tow cable
2) Array
3) Depressor.

Since depressor towing performance is a function of all three components, and since different components were used during the various phases of the depressor towing test, it is important to note which components were used for the design, and for model basin and at-sea tests.

2.1 TOW CABLE

All towed systems are strongly influenced by the tow cable used. The ideal tow cable has high strength, low drag and develops no side force. Under ONR sponsorship, DTNSRDC has continued the development of an integrated tow cable to the point where it shows great promise of being the ultimate tow line for high speed towing. The latest integrated tow cable design has a 2.16 inch (55 mm) chord, 0.48 inch (12 mm) thickness and a breaking strength of 28,000 pounds (124.5 kN), with a drag coefficient of 0.12. It appeared that continued development would eventually result in even higher strength, thus the characteristics of the depressor model were selected to produce the necessary tow cable tension to meet the goals with the integrated tow cable without concern for the resulting low cable factor of safety.

When the half-scale model was built for the model basin towing tests at DTNSRDC, it was fitted with a 0.347-inch (9 mm) diameter tow cable 6-feet (1.8 mm) long with Flexnose fairings 0.5-inch (13 mm) thick by 2-inch (51 mm) chord. The wetted length of test cable was short enough for the cable tension and angles at the test carriage to be essentially the same at both ends. This had the benefit of permitting angle and tension measurements to be sensed at the carriage, but the disadvantage of the nearly vertical cable generating a ventilation path that ran down the cable. A trailing horizontal plate at the water surface eventually solved the ventilation problem.

For the ONR sponsored full-scale trials aboard the R/V ATHENA in 1981, MAR Inc. furnished a Flexnose faired, Vector built tow cable that was considerably larger and weaker than desirable to develop the full design capabilities of the

depressor design. However, its published characteristics indicated suitability for demonstration purposes providing maximum speed, depth and cable scope were not attempted simultaneously. Figure 1 is taken from the Vector product information sheet for this cable. The Fathom fairings were as follows:

Chord: 3.5" (89 mm)
Length: 4.0" (102 mm)
Thickness: 0.95" (24 mm)
Inside diameter: 0.68" (17 mm)
Total length: 800 feet (244 m)

The fairings were prevented from sliding down the cable by rings swaged and bonded to the cable at ten foot (3.05 m) intervals. The fairing above each ring was notched out to receive the ring thus presenting a relatively smooth surface. Connecting links were used between all fairing segments including over the rings. The fairings were a loose fit with the cable at zero tension.

2.2 ARRAY

The depressor "pay load" is the hydrodynamic drag imposed by towing a neutrally buoyant linear sonar array. The drag of such an array is given by the expression

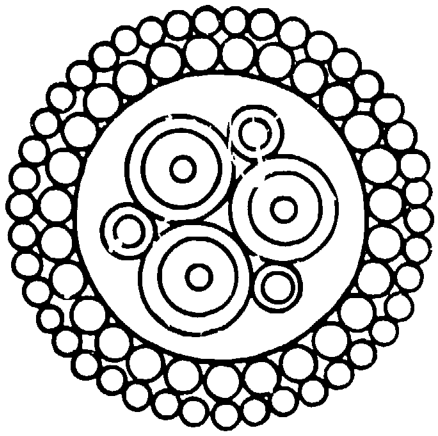
$$D_A = KCdLV^2 \text{ pounds (Newtons)}$$

where

V = towing speed in knots
L = array length in feet (meters)
d = array diameter in inches (mm)
C = drag "coefficient" 0.0019 for smooth arrays
K = units conversion = 1 (.575)

During the initial study phase of the EDO sponsored depressor program (ED-108), a standard array was assumed having a diameter of 3 inches (76 mm) and a length of 500 feet (152 m) resulting in dL = 1500 (11550). These smooth arrays have a drag coefficient of 0.0019 resulting in a drag of 5770 pounds (25.6 kN) at 45 knots and 3500 pounds (15.6 kN) at 35 knots.

Description:
TOW CABLE CONTAINING (3) MODIFIED RG-58U, (3) #18U, A PVC BELT AND OVERALL DOUBLE ARMOR.



(3) MODIFIED RG-58U COAX'S, #20 AWG, 7W, STC CONDUCTOR WITH A .040" WALL OF EPC, A #36 AWG (.005") STC BRAID WITH AN OVERALL .020" H.D.P.E. JACKET, BLACK, NOM. O.D. = .176"

(3) #18 AWG, 19W, STC CONDUCTOR WITH A .020" WALL OF EPC, COLORED. NOM. O.D. = .086"

PVC BELT AND FILLERS (INTEGRAL EXTRUSION, .035" WALL OVER APEX, NOM. O.D. = .380" (10mm)

INNER ARMOR: 27/.052" GIPS, NOM. O.D. = .544" (14mm)

OUTER ARMOR: 43/.039" GIPS, NOM. O.D. = .622" (16mm)

Specifications:

ELECTRICAL:

NOM. D.C. RESISTANCE AT 68½F: COAX, #20 AWG = 10.7 OHMS/KFT.
COAX BRAID = 5.5 OHMS/KFT.
#18 AWG = 6.9 OHMS/KFT.

INSULATION RESISTANCE, MINIMUM:
COAX CENTER TO BRAID = 1,000 MEGOHMS/KFT.
#18 AWG = 500 MEGOHMS/KFT.

VOLTAGE RATING: COAX = 1,000 VOLTS
#18 AWG = 500 VOLTS

ATTENUATION AT 1 MHZ, CALCULATED: 4.4 DB/KFT.

MECHANICAL:

BREAK STRENGTH:	24,000 POUNDS (107KN)
CALCULATED WEIGHT IN AIR:	535 POUNDS/KFT. (7.8N/M)
CALCULATED WEIGHT IN SEA WATER (SG=1.027):	415 POUNDS/KFT. (6.1N/M)
MIN. RECOMMENDED SHEAVE DIAMETER:	21 INCHES (533mm)

Figure 1. Tow Cable for Full Scale Depressor

A low noise high speed array study sponsored by ONR indicated the possibility of a much lower drag array made up of sections totaling 50 feet (15.2 m) of 6-inch (152 mm) diameter and 550 feet (168 m) of 1-inch (25.4 mm) diameter for a dL = 850 (6580) resulting in 3270 pounds (14.54 kN) at 45 knots and 1980 pounds (8.8 kN) at 35 knots.

To simulate array drag, rope drogues were provided by DTNSRDC for use in the towing basin trials of the half-scale model and both the basin trials and R/V ATHENA trials of the full scale depressor. They were lengths of braided nylon rope. Tests of the 100 feet (30.5 m) of one-inch diameter (25.4 mm) rope used for the half-scale model indicated the drag "coefficient" to be 0.0049 and 0.0062 for the 153 feet (47 m) of 2.1-inch (53 mm) diameter Samson 2-in-1 Power Braid nylon covered polypropylene used with the full scale depressor.

The Gould CID array used during the R/V ATHENA tests consisted of a number of neutrally buoyant modules forming a 197 foot (60 m), 3.05-inch (77 mm) diameter section towed by 100 feet (30.5 m) and later 400 feet (122 m) of 0.37-inch (9.5 mm) diameter stub cable. The stub cable has a weight per foot of 0.113 pound (0.5 N) in water plus a modest weight of connectors. The dL was 640 (4900) with 100 feet (30.5 m) of stub cable and 750 (5780) with 400 feet (122 m) of stub cable resulting in drags of 2460 and 2890 pounds (10.9 and 12.8 kN) at 45 knots and 1490 and 1750 pounds (6.6 and 7.8 kN) at 35 knots.

2.3 DEPRESSOR

The depressor design resulting from the ED-108 program and common to both the half-scale model and the full-scale demonstration depressor is depicted in Figure 2. Table 1 presents a summary of pertinent dimensions. This design is capable of meeting the ultimate goals providing the balance of the system is compatible. In particular the array drag and the tow cable drag and strength must be consistent with the assumptions.

The depressor has an NACA 0015 section fixed mid-wing, with a 4.5° negative incidence on a truncated TMB EPH shaped body. It's zero incidence NACA 0015 section tail is used to permit being located on top and clear of the tow staff wake. It is located on top primarily for handling considerations but the resulting roll moment favors stable operation.

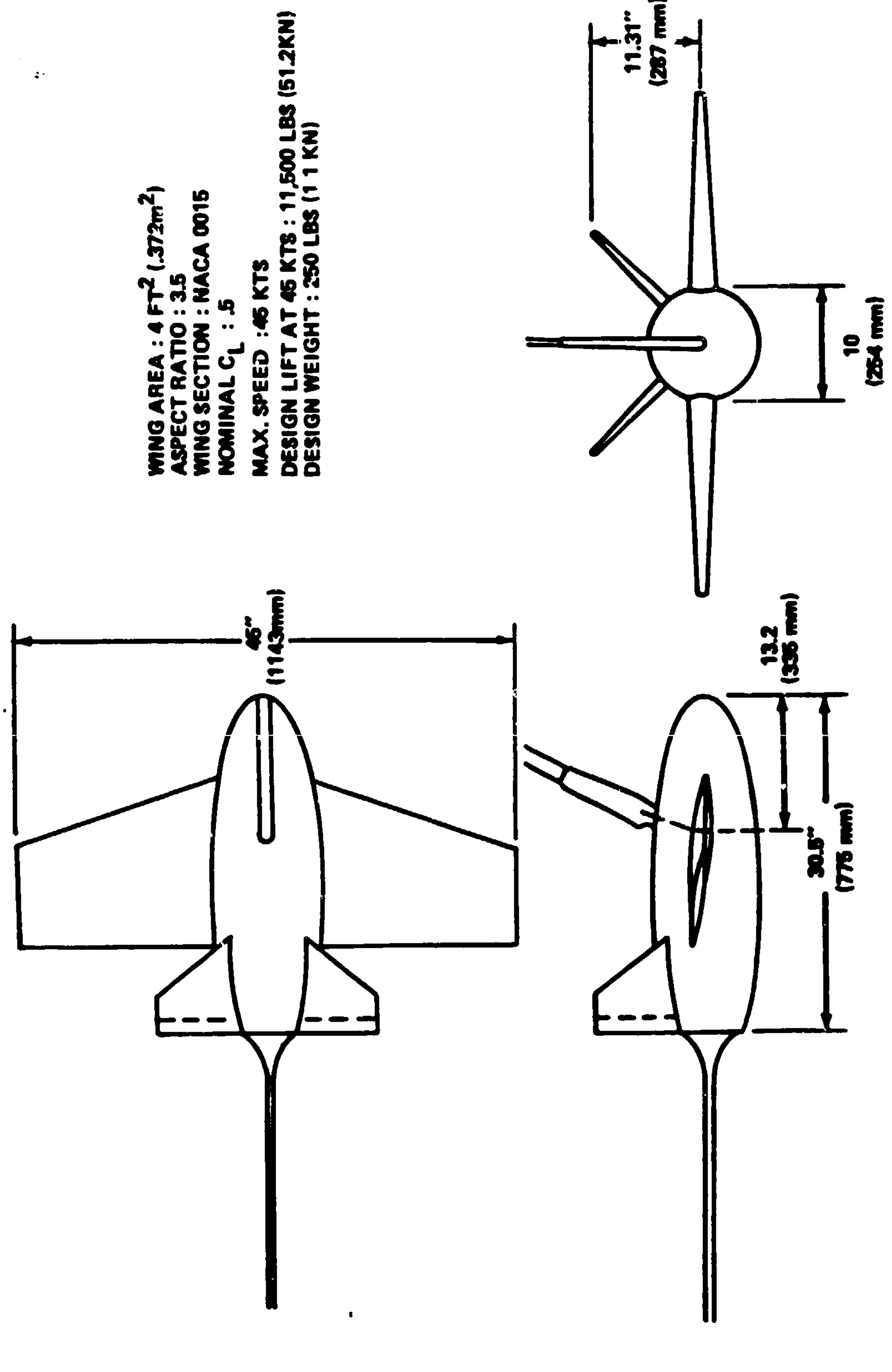


Figure 2. Depressor Design

TABLE 1. EDO DEPRESSOR PERTINENT DIMENSIONS

GENERAL

Body Shape - EPH DTMB R495 Table 1

Reference length = 35" (889 mm)

Body max dia. = 10" (254 mm)

Length to tail trailing edge = 30.5" (775)

Wing span = 45" (1143 mm)

Overall height = 16.4" (417 mm)

Towpoint = 13.2" (335 mm) aft of nose

WINGS

NACA 0015 section

Aerodynamic center 13.5" (343 mm) aft of nose (25% chord)

Wing span = 45" (1143 mm)

Area - total with included body = 4 ft^2 (0.372 m^2)

Mean chord = 12" (124 mm)

Taper ratio = 0.6

Aspect ratio = 3.5

Incidence = 4.5°, leading edge down

TAILS

Vee configuration (trailing edges 45° from vertical)

Full span trailing edge control surfaces

NACA 0015 section

Span = 12" (124 mm) from body

Total Area (true) = 1 ft^2 (0.093 m^2)

Mean chord = 6" (152 mm)

Taper ratio = 0.41

Aspect ratio = 2.0

Flap area ratio = 0.20

Incidence = 0°

WEIGHT OF FULL SIZE

In air = 265 pounds (1180 N)

In fresh water = 180 pounds (800 N)

WEIGHT OF HALF SCALE MODEL

In air = 29.5 pounds (131 N)

In fresh water = 21.5 pounds (96 N)

The tow staff is mounted on a transverse trunnion located on the body centerline 13.2 inches (335 mm) aft of the nose. This places it 0.30 inches (7.6 mm) forward of the wing aerodynamic center taken to be at 24 percent of the mean chord. A body pitch angle of 4.0 (i.e., a wing angle of attack of 8.5) degrees produces a conservative lift coefficient, C_L, of 0.5 which combined with the wing area of 4 square feet (0.37 m^2) results in a C_LS of 2 ft^2 (0.186m^2).

The drogue or array "stub" cable is attached to the aftermost part of the body centerline where the EPH shape of the body based on a length of 38 inches (965 mm) is truncated to 30.5 inches (775 mm). This produces a shorter body for handling purposes and a flow separation base drag that enhances the directional stability of the body.

The depressor is ballasted with a heavy nose to bring the center of gravity forward enough so that, combined with the buoyancy forces, the depressor hangs slightly nose down when submerged. When hoisted clear of the water by the tow cable it hangs tail down except that, with the ship underway, array drag causes the tail to swing aft to place the body in a more horizontal position. In that position the body gains roll stability because the roll axis between the array attachment point and the top of the tow staff then passes above the center of gravity. This prevents the depressor from capsizing when hoisted clear of the water. Likewise, when submerged, it is the location of the center of gravity below the top of the tow staff that creates a moment to return the depressor to a zero roll angle. However, at speed, the hydrodynamic lift of the wing is so much larger than gravity forces that unsymmetrical lift is capable of causing roll with resulting yaw and kite. Yaw moment adjustments by "rudder" deflection of the Vee tail trailing edge flaps provides compensation. The half scale model provided "screwdriver" flap adjustment and, although in test proven unnecessary, a pendulum operated flap control. The full scale depressor had both screwdriver adjustment and an optional shipboard controlled electric motor driven adjustment. In addition, the full size demonstration depressor had provision for a manual shift of the lateral location of the tow staff.

The main purpose of tail trailing edge flaps is to change the depressor depth by changing the wing angle of attack through pitch angle changes. Flap angle change was a screwdriver adjustment on both the half scale model and the full scale depressor. The same electric remote flap drive that could be used for "rudder" flap adjustment could be manually switched to pitch angle flap adjustment.

A unique array feed through handling concept had a strong influence on the design. This concept is illustrated in Figures 3 and 4. This concept eliminates the need for making and breaking watertight electrical connections during deployment and retrieval. Upon retrieval the bulky portion of the depressor, consisting of the outer shell which includes the wings and tail surfaces, remains fixed in a deck cradle as the cylindrical central section of the body is pulled out of the outer shell by the tow cable and staff. The array, still attached to the aft end of the central body section is then pulled through the cylindrical hole in the outer shell and reeled up on a section of the winch drum adjacent to the pocket in the drum provided for body stowage. The maximum length of the body was influenced by the practical size of a stowage pocket in the winch drum. The diameter of the body and shell was ten inches to provide adequate strength to carry wing and tow staff loads and provide room within the body for instrumentation and service connections permitting breakdown of the system into its major parts as well as means for remote adjustment of the flaps.

2.3.1 Design Performance

The towing tension and the necessary wetted scope of 0.48 inch (12 mm) thick integrated tow cable to attain a 500 foot (152 m) depth at 45 knots are presented in Figure 5 as a function of various depressor sizes assuming a depressor hydrodynamic lift to drag ratio (L/D) of 6. The depressor size is characterized by the lift coefficient times wing area (C_LS) and can be converted into lift by

$$\text{Lift} = C_L S \frac{\rho}{2} V^2$$

Depressor lift and weight combined with the drag of the array, depressor, and tow cable create cable tension. Selection of depressor size is a tradeoff between the desire for low cable tension and a short tow cable. Figure 5 shows that the maximum tow tension at 45 knots has a broad minimum value in the range of C_LS 1.8 ft^2 (0.167 m^2) whereas the necessary cable scope for a 500 foot (152 m) depth reduces appreciably with increased C_LS. A C_LS value of 2.0 square feet (0.186 m^2) feet (229 m) was selected for this design. Down force vs speed and depth vs. speed for this combination are presented in Figure 6. Unfortunately, the 28,000 pound (124.5 kN) breaking strength of the 0.48 inch (12 mm) thick integrated tow cable results in a safety factor of only 1.2 at 45 knots. As speed is decreased, the factor of safety increases to 2.5 at 31 knots and 3.0 at 28 knots. An improved higher strength to thickness cable must be used to reach the goal of 45 knots at a depth of 500 feet (152 m).

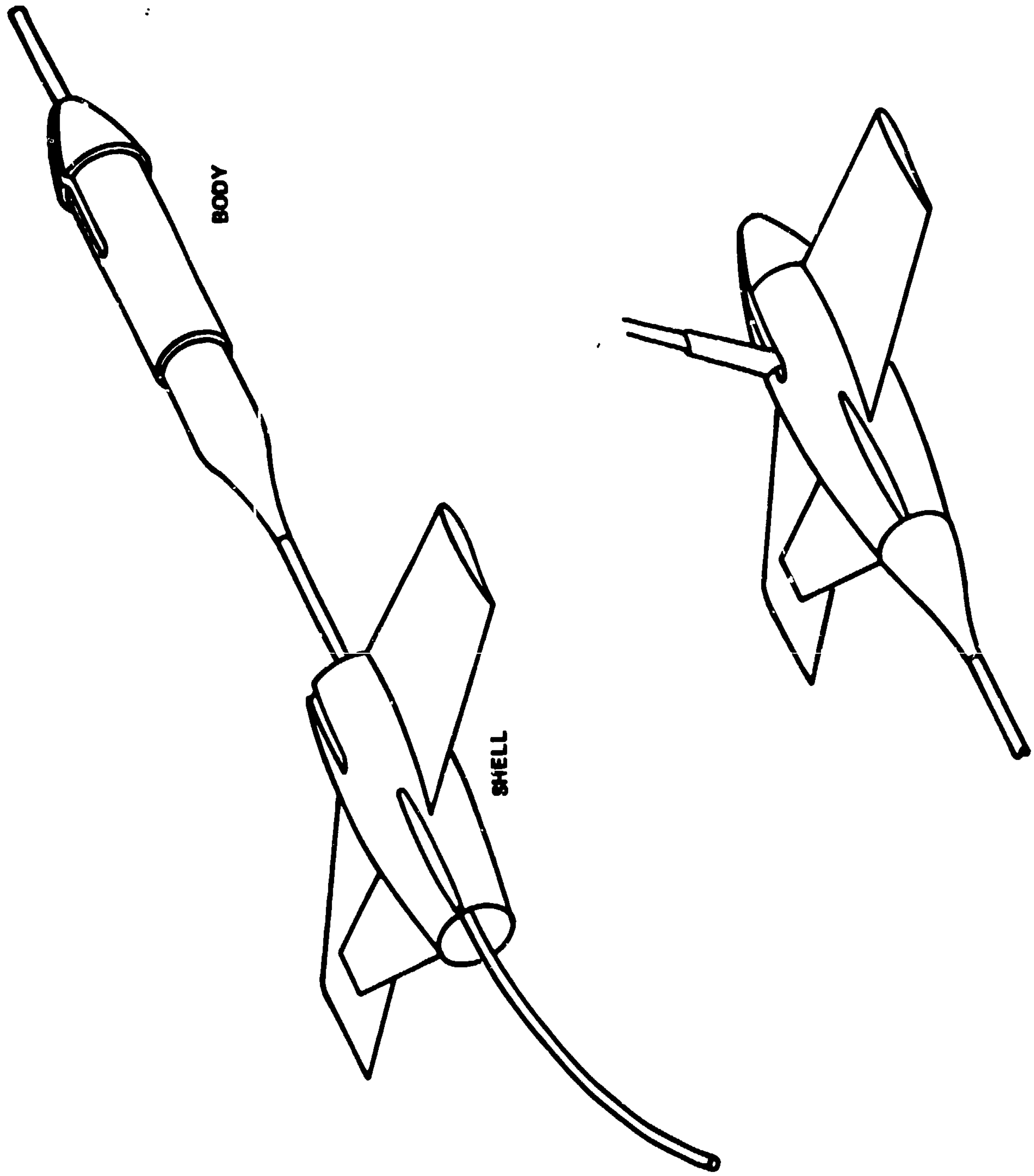


Figure 3. Feed Through Depressor Concept

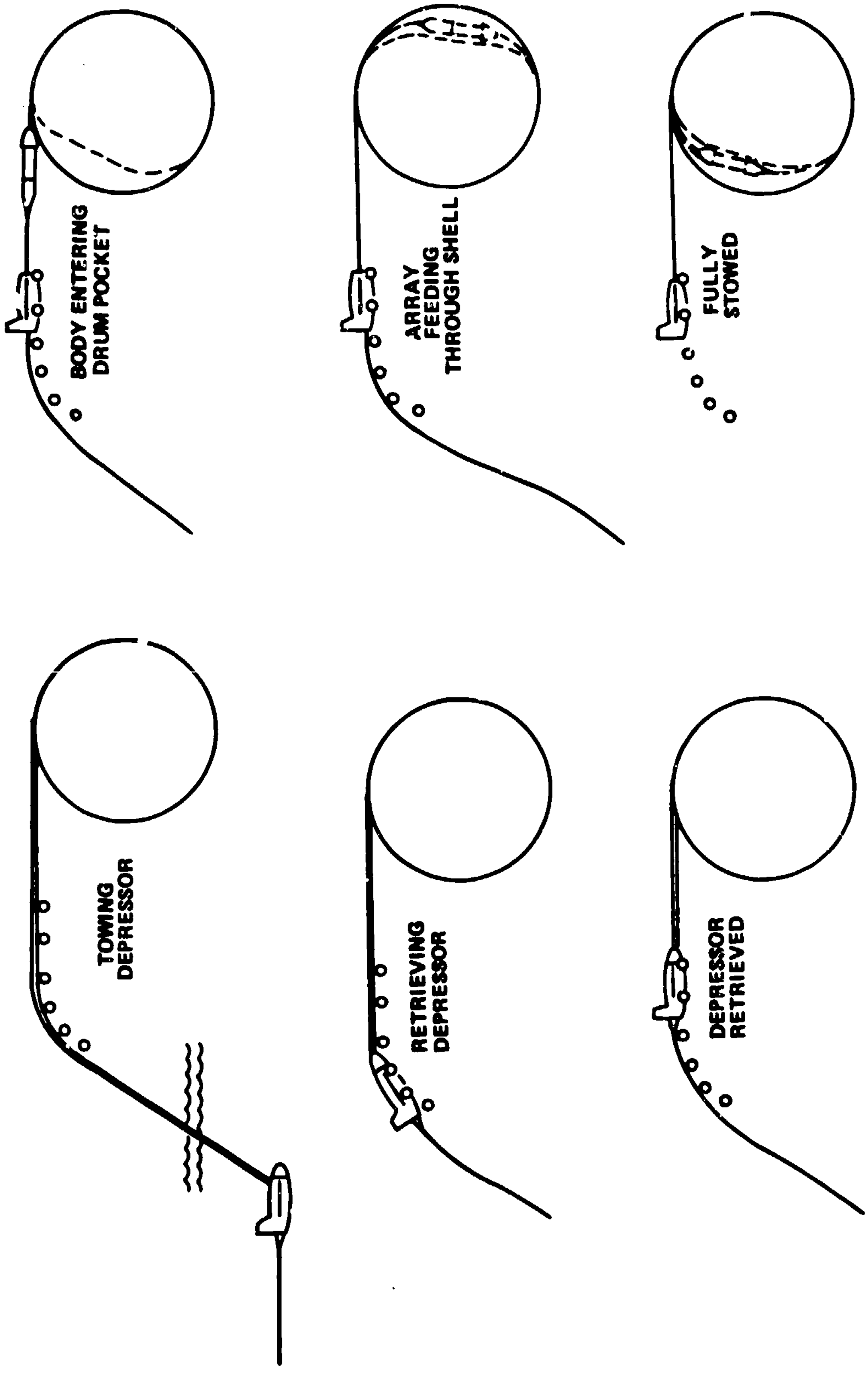


Figure 4. Handling Concept

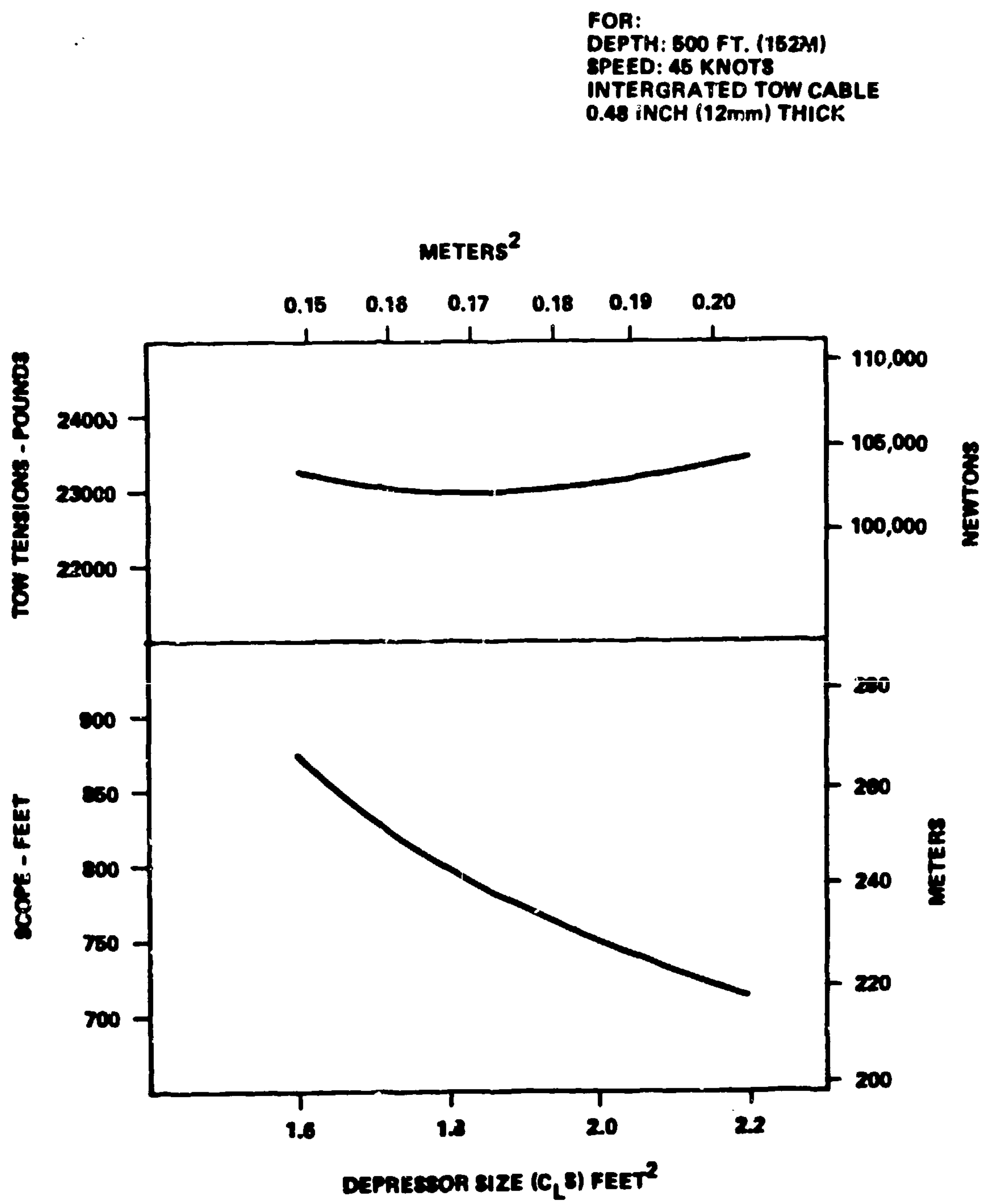


Figure 5. Predicted Scope and Tension vs Depressor Size

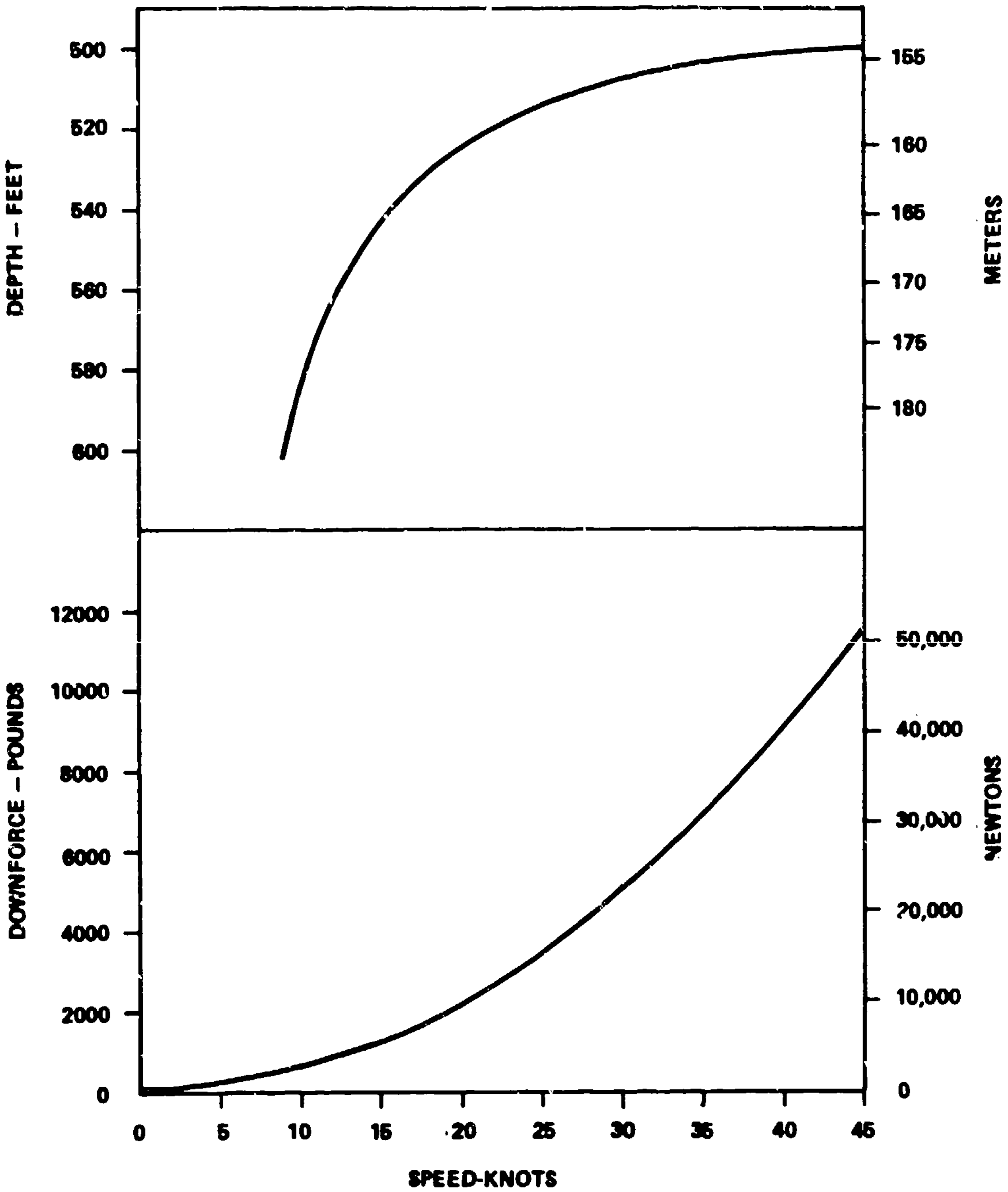


Figure 6. Predicted Depressing Force and Resulting Depth vs Speed for $C_L S$ =2 Ft^2 (0.186 m^2)

3. MODEL DESCRIPTIONS AND TESTS

The testing of the depressor was divided into three phases. These were:

Phase 1: Half-scale model tests at DTNSRDC towing tank

Phase 2: Full scale demonstration tests at DTNSRDC towing tank

Phase 3: Full scale demonstration at-sea tests.

Each of the phases are discussed in detail in the following paragraphs.

3.1 PHASE 1 - HALF-SCALE MODEL TESTS

The half-scale model (shown in Figure 7) was designed and fabricated for towing in the model basin to demonstrate its hydrodynamic performance. The results of this test were used for comparison purposes with a competing model by Mar Inc. to assist DTNSRDC in making technical recommendations to ONR regarding further development of high speed towed array depressors. No attempt was made to demonstrate the operation of the feed through array handling feature. This made it possible to design adjustment features into the model that would not be required on a final full size unit, namely:

a) The tow staff longitudinal location-final location: 0.02 inch (0.5 mm) forward of wing CP full scale

b) The wing incidence angle-final angle: 4.5 deg L.E. down

c) The tail surface incidence angle-final angle: zero degrees

d) The center of gravity longitudinal location-final location: such as to cause slight nose down pitch in water

e) The center of gravity vertical location-final location: slightly below centerline but not recorded

f) The total weight-final in air-full scale: 250 lb (1.1 kN)

g) The tail trailing edge flap "rudder" action controlled by a lateral pendulum (for use only in the undesirable event of marginal longitudinal stability) - found to be unnecessary)

h) Variation of tail flap section shape-final selection: full length 1.2-inch (30.5 mm) chord, section tapered from 0.50-inch (13 mm) thick at pivot line to 0.25-inch (6.4 mm) thick at squared off trailing edge full-scale

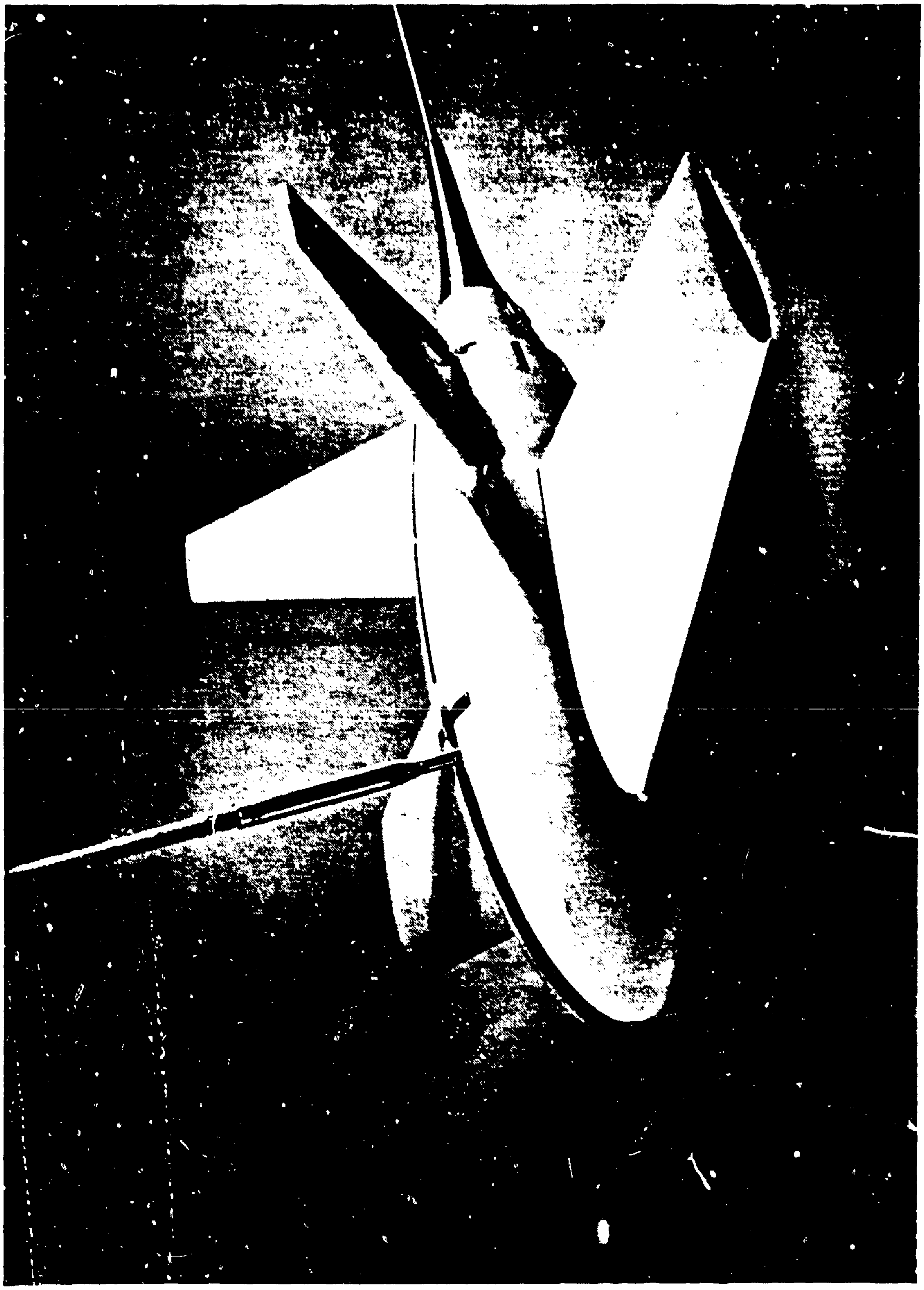


Figure 7. Half Scale Model Depressor

Model testing was conducted in the high speed towing basin at DTNSRDC during the first quarter of 1980. The basin contains fresh calm water disturbed only by the previous passage of the model. It is considered a scale equivalent of ocean conditions beneath the surface. The model was towed by a 6 foot (1.83 mm) Fathom Flexnose faired cable from a carriage which rides above the water carrying the test equipment and personnel. Carriage numbers 5 and 6 were utilized. The testing arrangement is schematically illustrated in Figure 3, supplied by DTNSRDC. Tension, cable angle, and kite angle at the carriage tow point were recorded as a function of speed. Still photos taken from the side photo pit provided the cable angle at the depressor. Motion pictures were taken from the carriage during the evaluation phase to provide a visual record of behavior.

The initial grooming phase for model trimming, adjustments, and modifications by EDO was followed in the second phase by the DTNSRDC evaluation of the depressor.

A tendency to kite to starboard at high speeds made model trimming difficult. The kiting was due to unsymmetrical wing lift caused by the method of wing manufacturing. The two identical wings were made by a tracing type machine operation. Any difference in contour between the upper and lower surfaces as machined became inverted when one wing was inverted and used for the opposite side of the model. Thus the differences became additive and caused a roll moment. After final model trimming, the kite was kept below 6 degree with the drogue and below 14 degrees without the drogue for all speeds. An imposed kite deflection gradually diminished toward the undisturbed value. It was concluded that active roll control is not required.

The EDO depressor design is stable, with the trailing edge flaps fixed, at carriage speeds to 29.7 knots (42 knots full scale) with the maximum lift to weight ratio of 56 to 1. The model has a strong tendency to head directly into the flow path, even when released from an intentionally imposed 90-degree yaw.

The high stability of the depressor was further demonstrated upon loss of the drogue during the highest speed run. At 29 knots carriage speed, the drogue attachment rope severed, the model shot forward (due to loss of drogue drag) and continued in its characteristically stable manner as if there had been no disturbance. Values measured at the tow point and from the tow staff angle at the body were recorded on photographs. The tow staff angles were measured from the photographs and compared to the angles recorded at the tow point. The difference

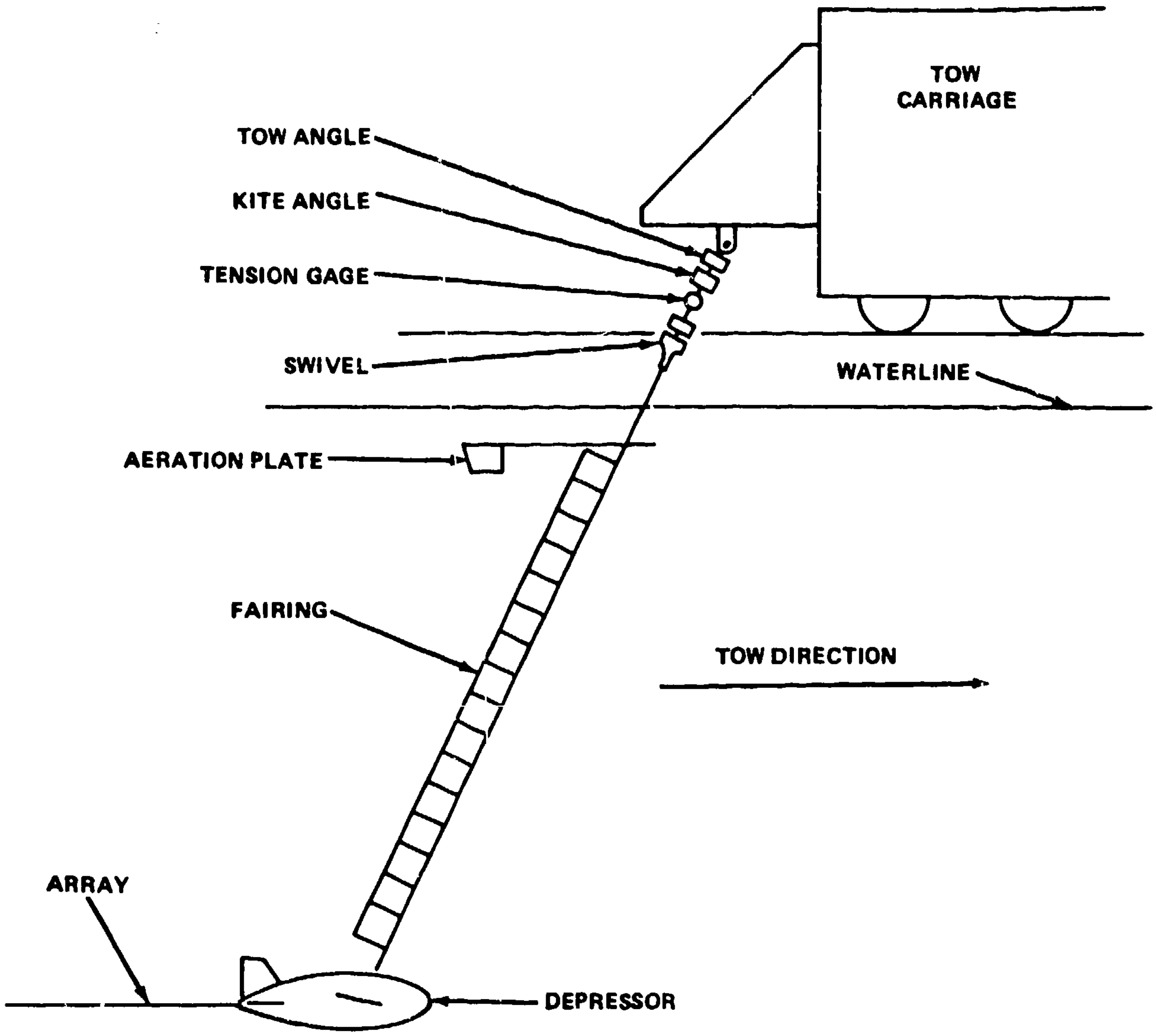


Figure 8. Experimental Arrangement

between the angle at the top and bottom of the tow cable average 5.5 degrees with all but one value being within ±0.5 degrees. The differences show no correlation with speed. The recorded values adjusted by the average value of 5.5 degrees are taken to be the tow staff angle at the body. This angle used in conjunction with the recorded tension determines the lift and drag.

The values of total depressing force are presented in Figure 9 from runs with the drogue. The values obtained are slightly higher than those necessary to meet the full-scale design condition as shown on Figure 6. The hydrodynamic lift coefficient is obtained after subtracting out the body weight, which has a significant effect at low speeds. The lift coefficient at 8.5 degree wing angle of attack is 0.55, which compares favorably to the design value of 0.50 used for depressor wing area sizing.

Figure 10 shows the hydrodynamic lift to drag ratio (L/D) averaging about 6.8 after depressor weight and drogue drag have been subtracted from total lift and drag.

3.2 FULL SCALE DEPRESSOR

The full-scale depressor was designed and manufactured at EDO, basin tested at DTNSRDC and towed at sea from the ATHENA. Figure 11 shows the full-scale model with tow cable and drogue attached. The object was to duplicate the full scale performance characteristics of the successful half scale model, to include the depressor features of the array feed through handling method, to include sensors for tow staff tension and angle, depressor roll, pitch and depth and to mate with the Flex-nose faired, Vector tow cable of Figure 1 and the Gould towed array. All of the variable adjustments of the half-scale model were eliminated and/or fixed at the best values selected from the half scale model tests except for the tail flap angle. The tail flap angle remained adjustable and was further improved by the addition of a remotely controlled electric motor drive that could either deflect the two flaps as rudders or, by a manual shift of the gearing, as elevators.

The depressor consists of two major assemblies as required by the array feed through handling concept shown on Figures 12 and 13. The shell assembly, consisting of the wings, vee tail and outer portion of the streamlining of the depressor, has a stepped cylindrical hole down the middle through which the array is fed and in which the body assembly, consisting of the ballast nose, tow staff, instrumentation and flap adjustment drive, is secured during towing. All electrics and electronics are associated with the body assembly which includes a pressure tight

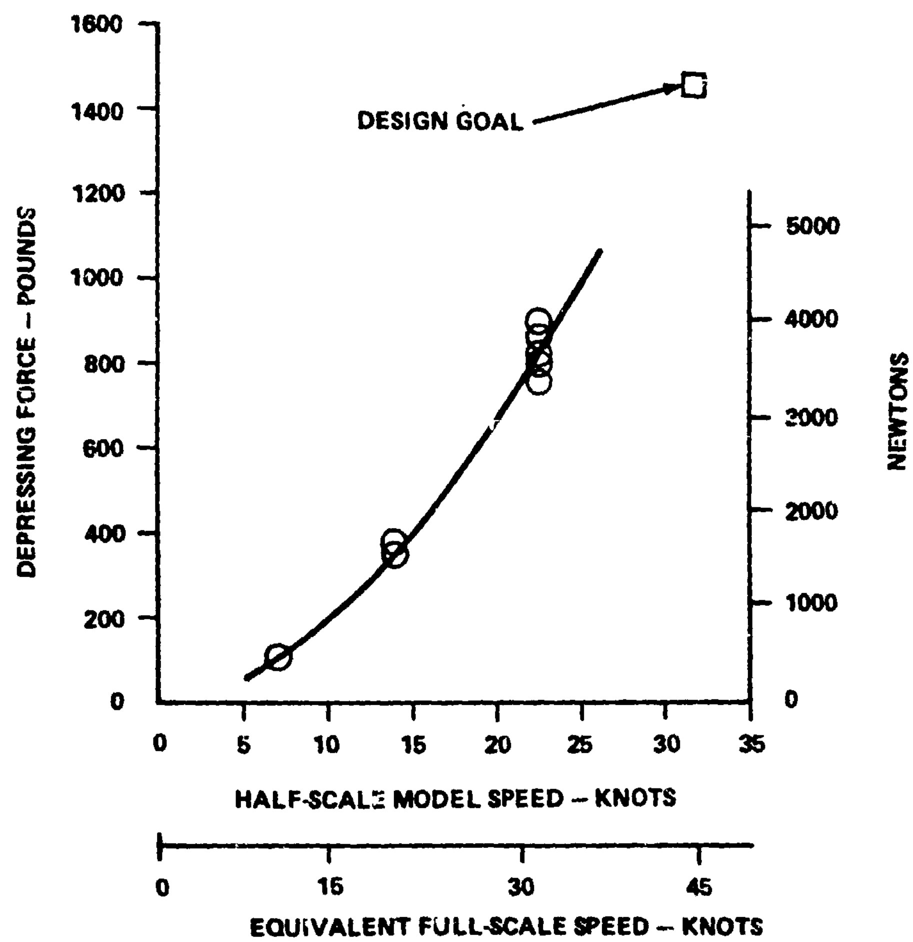


Figure 9. Half-Scale Model Depressing Force vs Speed

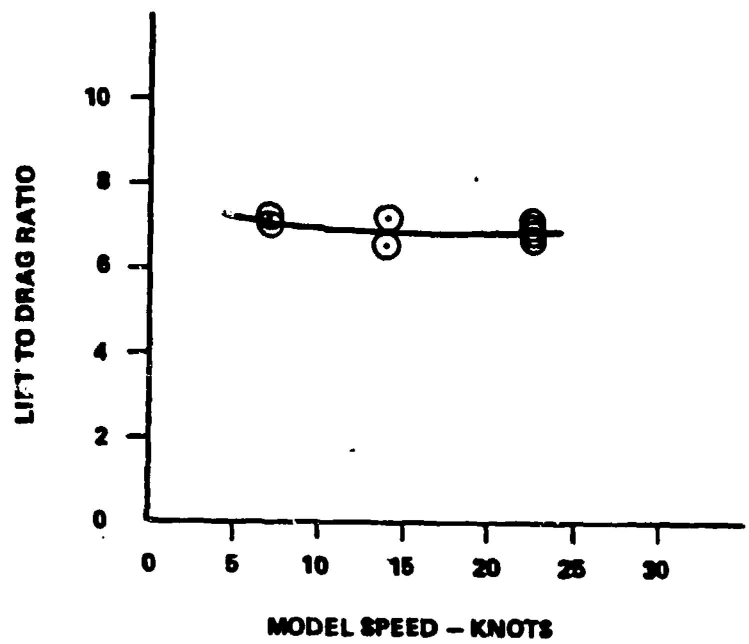


Figure 10. Half-Scale Model Hydrodynamic Lift to Drag Ratio

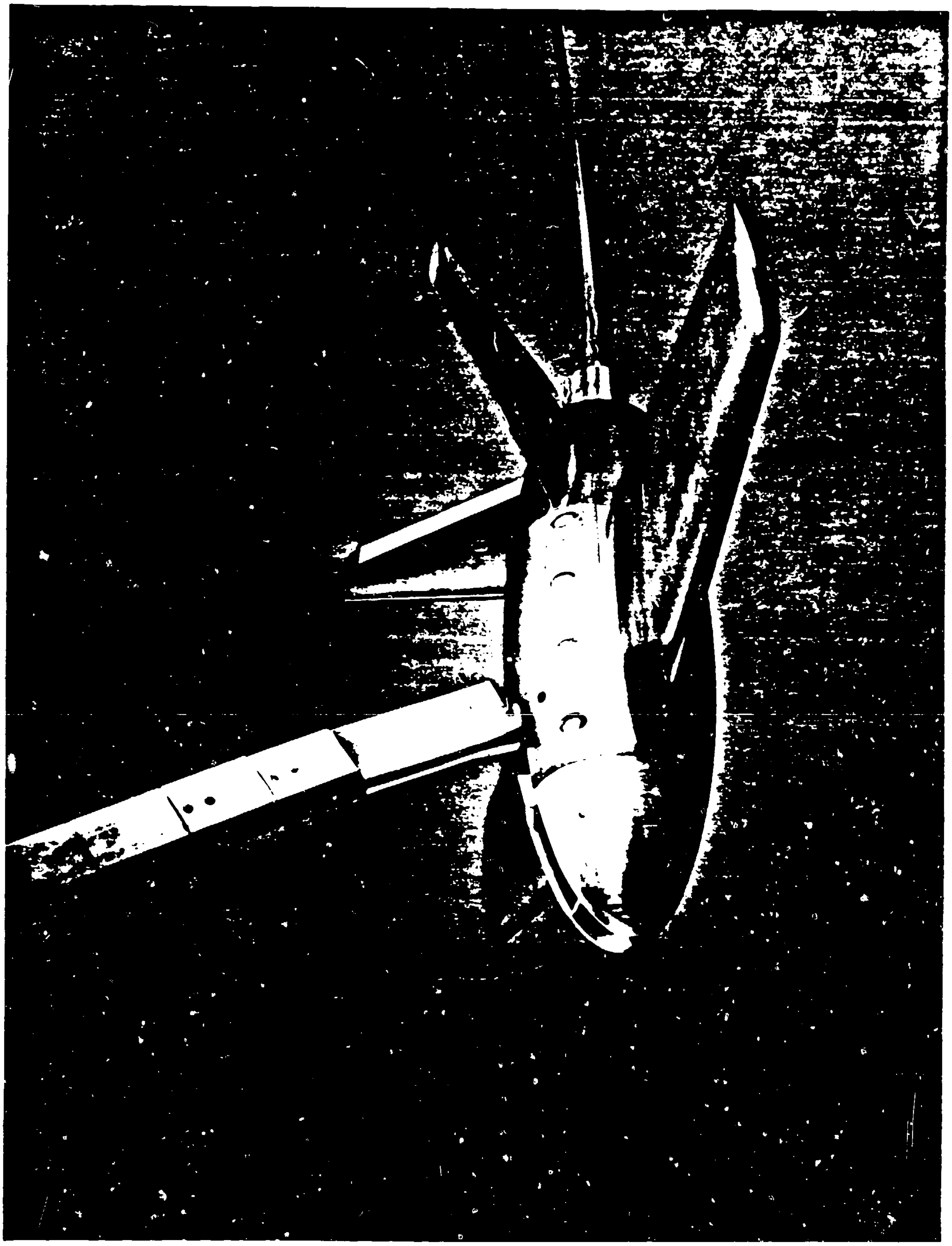


Figure 11. Full Scale Depressor

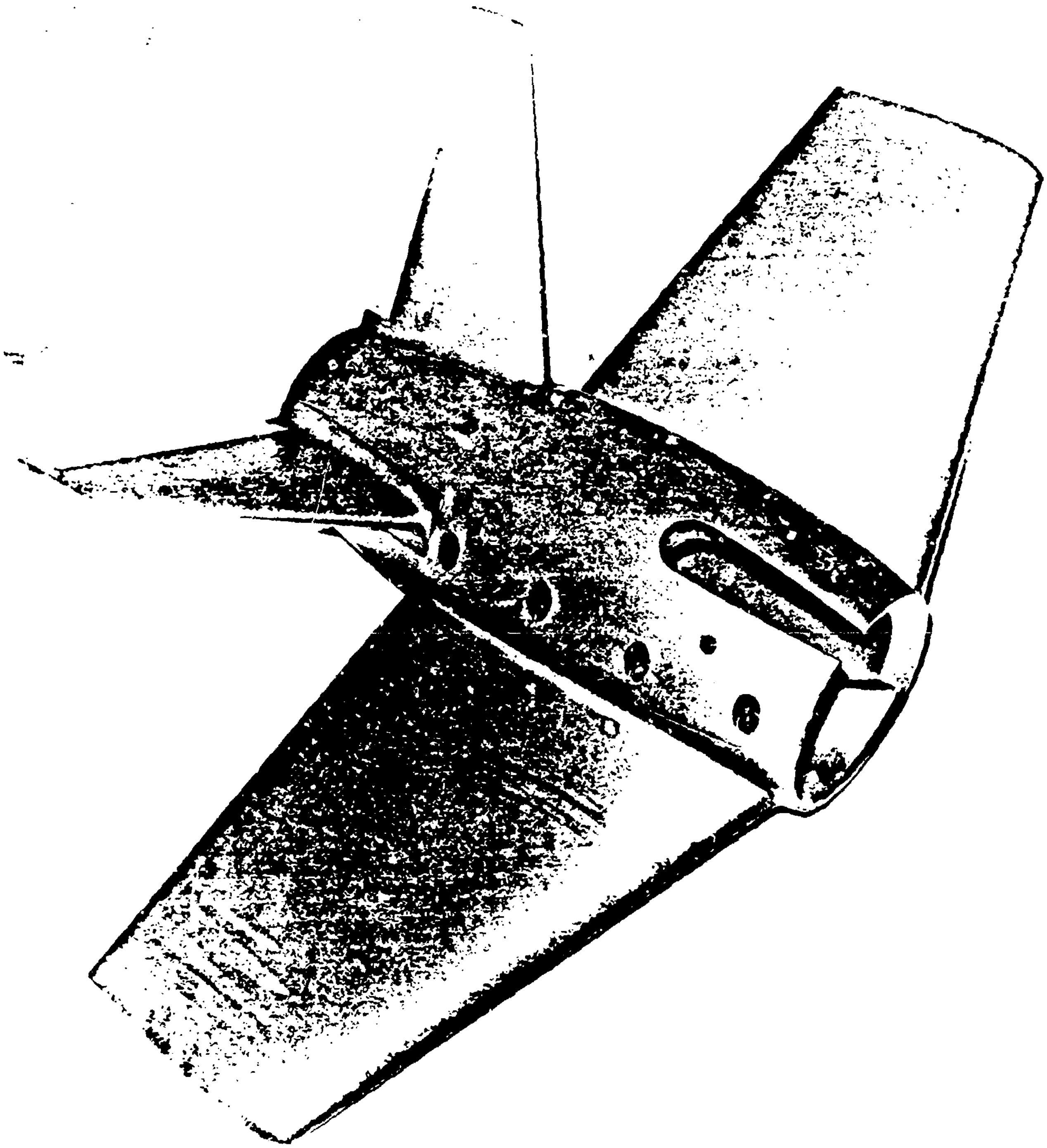


Figure 12. Shell and Wing Assembly

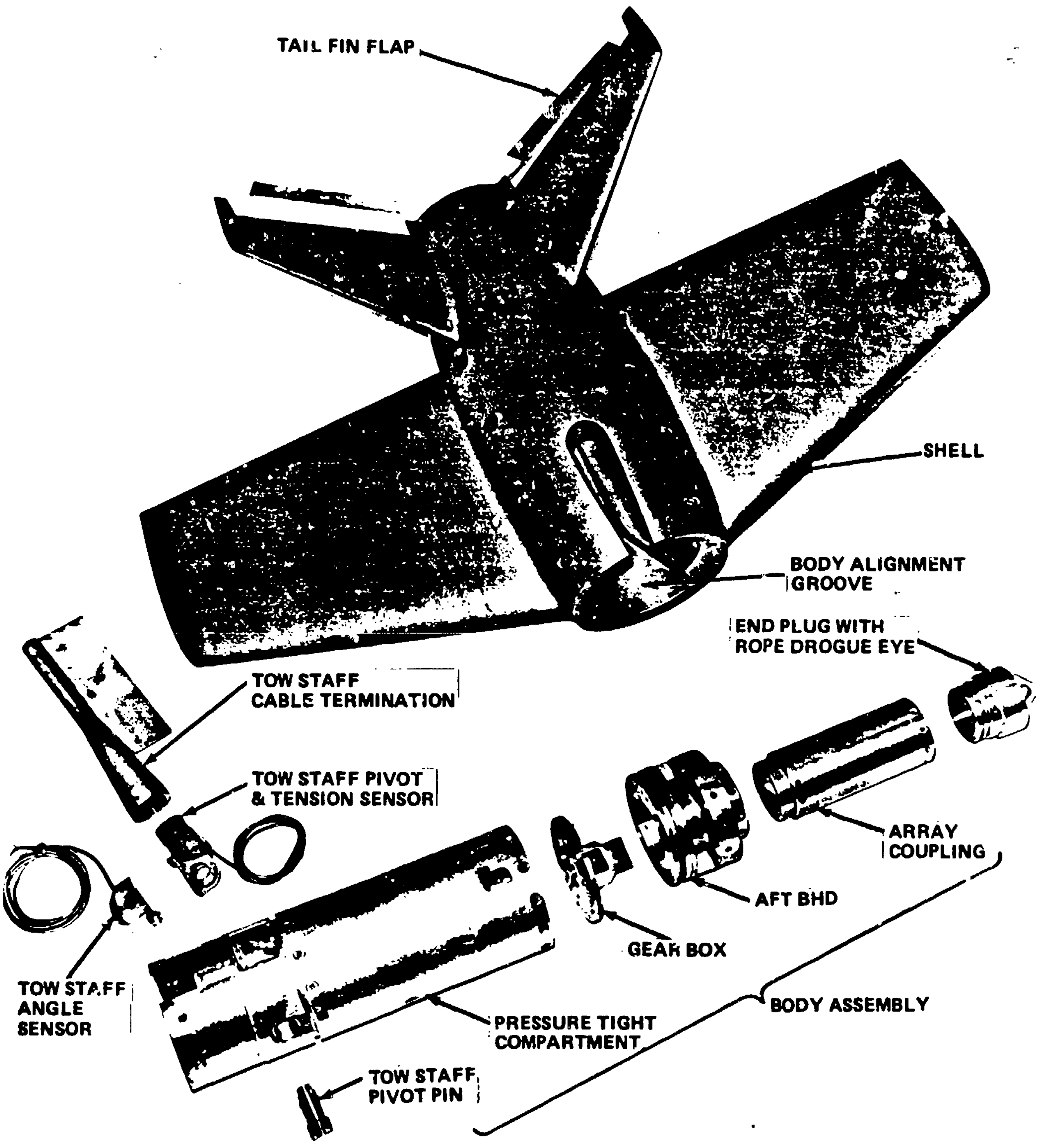


Figure 13. Depressor Components

compartment and the only contact with the shell is mechanical. One reproducible copy of each drawing of the complete set of manufacturing drawings has been delivered to ONR Code 220. The list of drawings is included as Appendix A of this report.

Because symmetry about the longitudinal vertical plane is vital to the successful towing of a light weight, high hydrodynamic lift depressor, the port and starboard wings pass beneath the body to form one integral member which was machined on NC equipment by Micro-craft, Inc., known for precision machining of wind tunnel models of superb quality. Unlike the half scale model, the port and starboard wings are machined from a single aluminum alloy billet each identical but to opposite hand.

This machining was bolted to the upper half of the shell. The two identical tail fins were then bolted to the upper shell to form the assembly of Figure 12. The tail flaps and their push rod actuating mechanisms were installed. The major aluminum parts, namely: wing, upper shell and the tail fins were hard coat anodized. All other aluminum parts were chromic acid anodized and stainless steel was passivated.

The body, consisting of the nose and a tubular section that slides freely into the six inch hole in the shell, is retained from sliding out again by a locking pin that engages a tab that protrudes down from the body tube into a groove machined in the lower or wing portion of the six inch hole. This groove widens as it approaches the forward open end of the hole. When the body enters the shell the tab rides in the groove and orients the body in roll so that the tow staff is on top and the flap operating gear is aligned. Some of the body parts are included in Figure 12.

Five test sensors are located in or on the body assembly of the depressor. They are to measure roll, pitch, tow staff angles from the vertical, tow staff tension and depth. The roll, pitch and tow staff angle sensors are pendulous potentiometers. Pitch and roll potentiometers are located within the pressure tight compartments and the tow staff potentiometer is potted and attached to the tow staff. The depth sensor is a pressure transducer threaded into the forward bulkhead of the pressure tight compartment so that it senses hydrostatic pressure behind the tow staff pivot. The tension in the tow staff is measured by four strain gages in a half bridge circuit pasted to the sides of the tow staff. The voltages from the sensors are connected to a strain-gage amplifier which amplifies the strain gage signals to a level equivalent to the levels of the pendulums and depth sensor. These signals are then applied to telemetry transmitters for transmission to shipboard demodulators and recording equipment, furnished by DTNSRDC.

The angles (pitch, roll and tow staff) gave no trouble and good data was obtained. The depth sensor was somewhat speed sensitive, thus while satisfactory for practical sonar shipboard operation, without proper calibration, proved unsatisfactory as a scientific test instrument. The tension measurements were of little value because of an error in the circuit which caused the temperature differences to strongly influence the tension readings.

The depressor is structurally designed to be stronger than the 24,000 pound (106.7 kN) ultimate strength tow cable. This force may be generated by the winch attempting to reel in the tow cable while the depressor is clamped to a deck cradle or by excessive depressor lift while being towed at excessive speed. When towed at 45 knots at the design pitch angle, thus developing the design lift coefficient of 0.5, the resulting force developed at the tow staff would be 11,500 pounds (51155 N) which is within the capability of depressor structural strength. However, the length of the tow cable must be limited to that resulting in a reasonable factor of safety at the ship end which is a function of the tow cable used. High speeds (to 45 knots) can be obtained using shorter cable lengths and have been demonstrated with 100 feet (30.5 m) of the tow cable of Figure 1 with flexnose fairings 0.9-inch (23 mm) thick by 3.5 inches (89 mm) chord.

The depth control is a manual, remote adjustment of the depressor tail flaps. To increase the towing depth of the depressor (and array), the trailing edges of both flaps are deflected downward by a stepping motor. Each step of the stepping motor deflects the flaps 0.045 degrees. The operator selects the direction the flaps will move with a switch labelled "UP - DOWN" and starts the motion with a switch labelled count "On-Off". Each step of the motor is then counted in terms of degrees of flap motion on a LED display. A third switch labelled "RESET" returns the counter to zero without the flaps moving.

When it is desired to move both flaps to the port or starboard together for rudder control, the gearing between the motor and flaps is manually shifted. This is done by removing a small lock plate in the depressor body, moving a shift lever and replacing the lock plate. The lables "PORT-STB" are read instead of "UP-DOWN" to determine the direction to throw the switch.

3.2.1 Full Scale Basin Test

The full scale demonstration depressor was towed at the DTNSRDC high speed basin from carriage number 5 on June 26, 29, and 30, 19[illegible]. Initial testing involved

troubleshooting mechanical aspects and instrumentation difficulties of the depressor and also preliminary trimming runs to demonstrate satisfactory depressor behavior. Earnest data acquisition initiated with run number 24.

Testing was relatively free of problems. One difficulty developed from play in the port flap which caused a speed dependent roll. This roll was not excessive, being within ±6 degrees in the set of runs after final trimming. Other difficulties included occasional tow cable ventilation, wing cavitation at high speed due to shallow depth and various minor mechanical and electrical difficulties.

The depressor performed very well. It exhibited excellent directional stability and tracking, with no excessive roll or kite. The depressor remote flap angle adjustment in the pitch (lift adjustment) mode was made at speeds up to 20 knots and the depressor responded. Above 20 knots, the time duration of the run was too small to positively ascertain the flap adjustment effect. Response to flap adjustment in the "rudder" (roll adjustment) mode was not investigated due to time limitations.

Hydrodynamic lift (depressing force) was obtained from the tow staff tension and angle with depressor weight subtracted and is plotted in Figure 14 for runs 49 through 54. The data agrees with the design goal of 7000 pounds (31.1 N) total depressing force at 35 knots when extrapolated from 30 knots to 35 knots, corrected for the angle of attack being only 7.4 degrees instead of the desired 8.5 degrees and adding back the 180 pounds (800 N) of depressor weight.

The depressor drag was obtained from the tow staff tension and angle with the calculated drag of the rope drogue subtracted and is also presented in Figure 14.

The depressor hydrodynamic lift to drag ratio (L/D) presented in Figure 15 was computed from the faired data of Figure 14, and results in an L/D of 6.8 from 15 to 30 knots.

3.2.2 ATHENA Trials

Sea testing of the full scale demonstration depressor was conducted from the R/V ATHENA in SEA TRIAL 1A6. The tests were conducted in the Exuma Sound in August 1981.

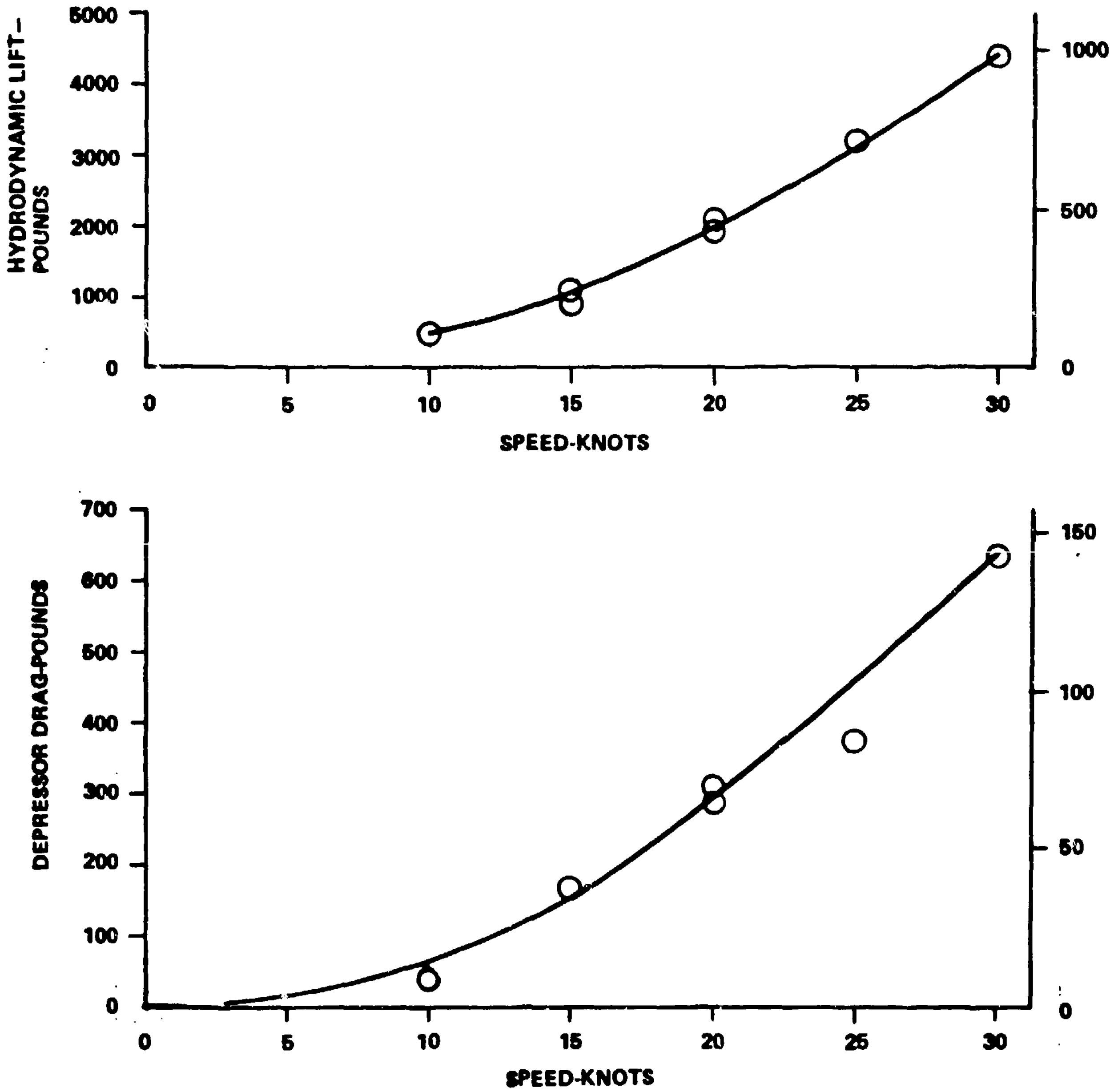


Figure 14. Full Scale Model Basin Test Results

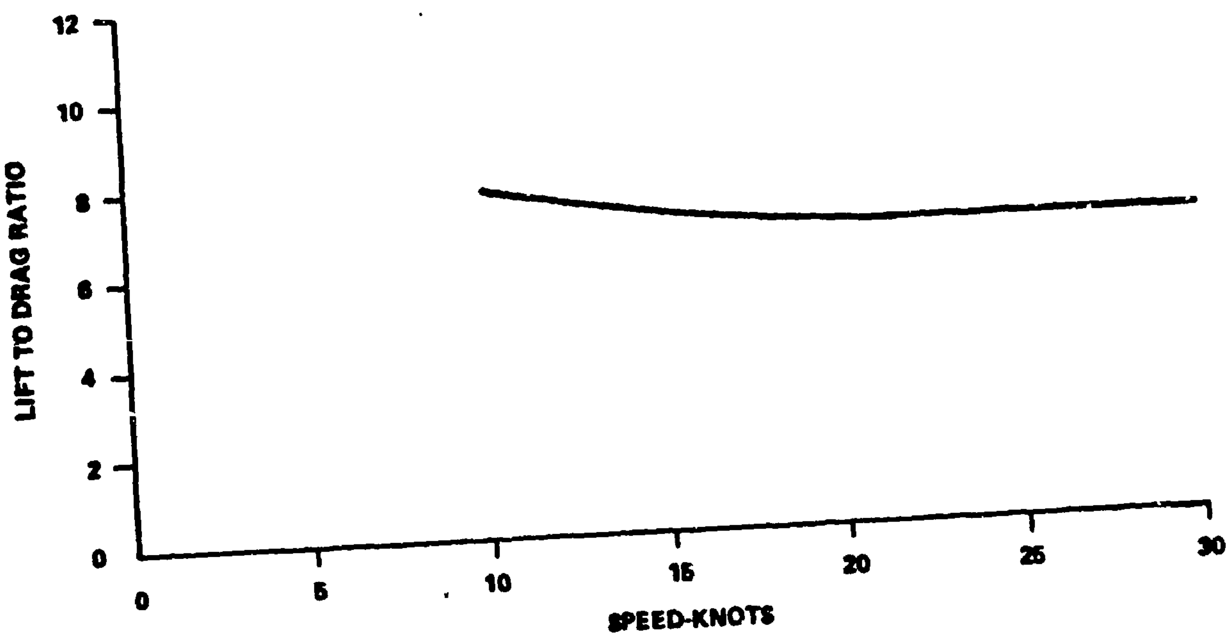


Figure 15. Full Scale Model Hydrodynamic Lift To Drag Ratio

Three one day trips out of Fort Lauderdale were conducted 30 July, 1 August and 2 August 1981 for the purpose of assuring that the depressor, tow cable, array and handling methods were ready for the sea trial.

It was determined that the tow staff tension instrumentation was faulty due to an error in the circuit which could not be corrected in time for the sonar trials. The loss of this tension data was a hydrodynamic disappointment but it did not affect operation or sonar results. The towing tension at the ship end of the cable was available.

The depth sensor had not been calibrated against speed during the basin trials and it indicated depth in excess of the known cable scope and the array depth meter readings. The accuracy is sufficient for sonar, but not for scientific hydrodynamic purposes.

The depressor towed well with and without the rope drogue. The data collected with the drogue and a 100 foot (30.5 m) tow cable scope is plotted in Figure 16.

It is noted that the kite angle is small and random with regard to both speed and roll angle. The cable tension at the ship is consistent with expectations but not having depth and tow staff tension data is unfortunate.

The advantage of a lightweight depressor was evident. No means for handling had been provided other than the reel for the tow cable, the tilting frame from which the tow sheave hung and a wood deck cradle. The body was hoisted clear of the water, hanging by the tow cable from the tow sheave and held in a tail aft and slightly tail down attitude by the stabilizing influence of the drogue. The frame was rotated forward as the cable drum operator payed in cable. A steadying hand or two grasped the wing and the depressor landed on the cradle.

Three hundred ninety seven feet of the 3.05-inch diameter Gould array with the full 400 feet of stub cable was then connected to the depressor body. The stub cable, unlike the array, weighted 0.113 pounds per foot. It was found that this additional weight applied to the aft end of the depressor could be offset by a 10 degree downward deflection of the flaps to permit towing, providing reasonable way was kept on the ship. The speed was increased in steps to 30 knots with the depressor pitch angle between 9 and 10 degrees, port roll generally 2 to 6 degrees and kite ± 9 degrees. It was noted that the indicated array depth was considerably

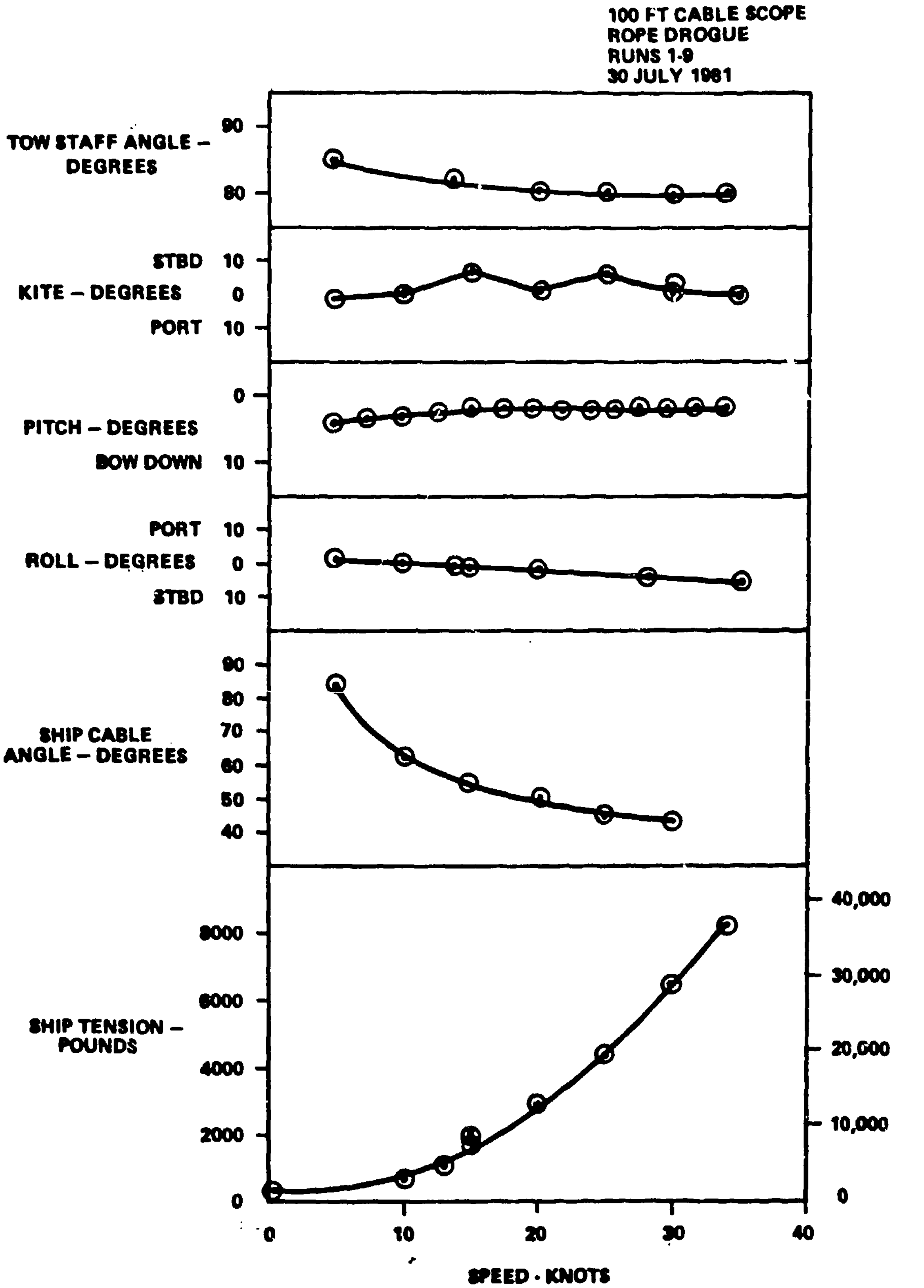


Figure 16. R/V ATHENA Test With Drogue

deeper than the tow cable scope payed out. After towing at 30.5 knots, the depressor abruptly assumed a 40 degree port roll angle and 38 degree kite angle causing the run to be terminated. (Plugs, fairing bolt holes forward of the tail fins, were found to have come out.) The data collected during this condition is too sparse and unreliable to include in this report.

It was concluded that the depressor was suitable for use in the depressor tow portion of the ONR Sea Trial 1A6 on the R/V ATHENA. The depressor was deployed during that portion of the trials occuring on 5, 6, 7 and 8 August 1981 in Exuma Sound. Data was recorded by the DTNSRDC furnished strip chart and digital computer/printer. The array depth readings were manually recorded when available.

Figure 17 shows the R/V Athena test configuration at 20 knots with the depressor towing 100 feet (30.5 m) of stub cable and 197 feet (60 m) of array with a tow cable scope of 780 feet (238 m). Figure 18 shows the data obtained in graphic form for these conditions. The flap angle was changed from 10.3 to 7.3 degrees down and the ship made a port turn of unrecorded magnitude during the run. Figure 19 is for the same condition except 400 feet (122 m) of stub cable and a constant flap angle of 10 degrees down.

The high starboard kite angles of these runs was of concern. It was noted that kiting had not been a problem during the day trips out of Fort Lauderdale until the sudden 40 degree port roll and accompanying 38 degree starboard kite. Before the Exuma Sound runs the bolt holes in the depressor were permanently plugged and faired. From then on no relation was seen between the sign or magnitude of depressor roll angle and cable kite angle. It was concluded that the cable fairings, not the depressor caused kiting. The reason for the tow cable fairings causing the kiting is elusive and not discussed herein.

Figure 20 shows the results of the remote pitch flap adjustments from the ship while underway. This data is from run 36 on 8 August 1981. No array or drogue was attached. This plot demonstrates the capability of remote adjustment from the ship.

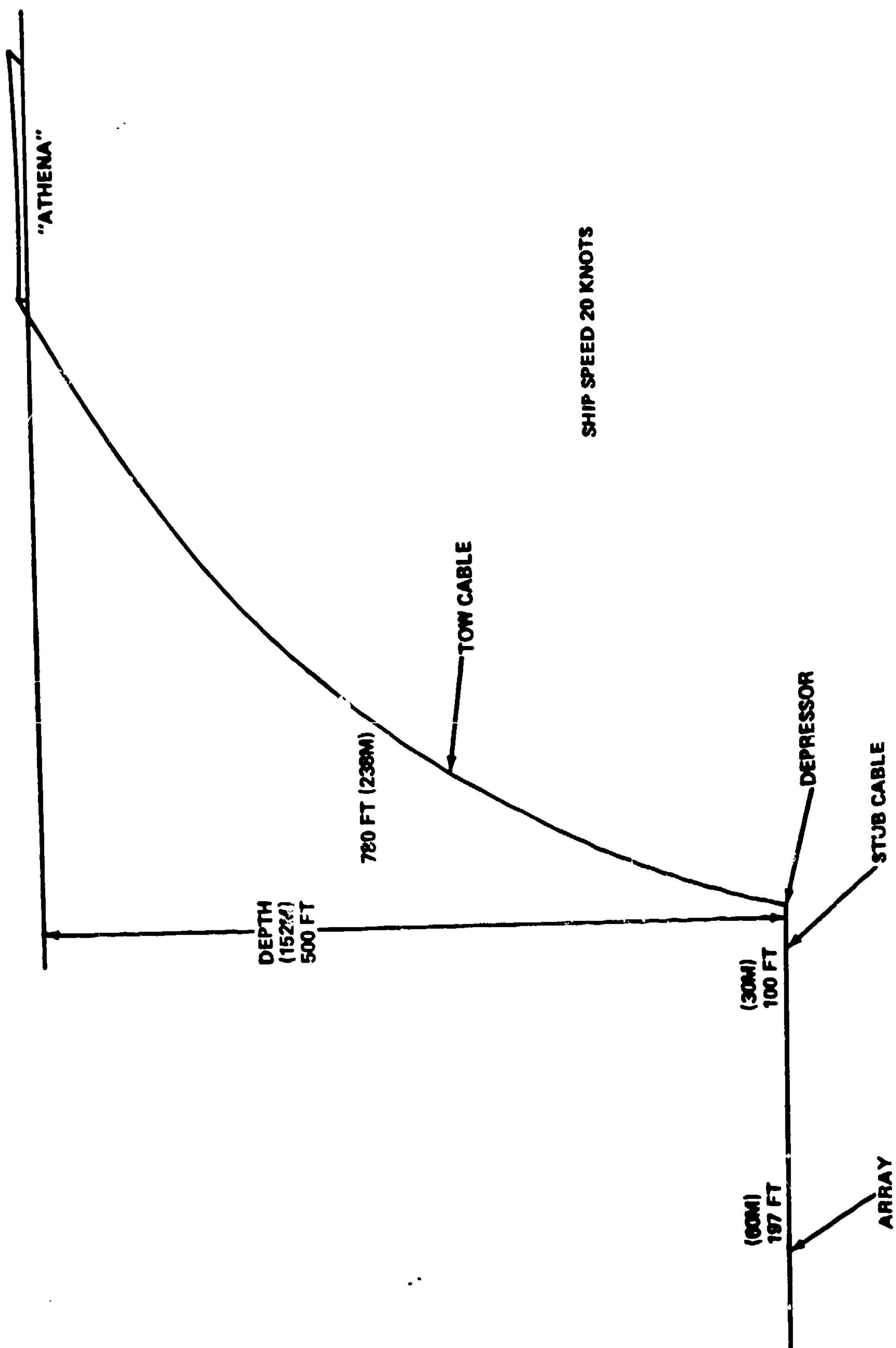


Figure 17. R/V ATHENA Test Configuration

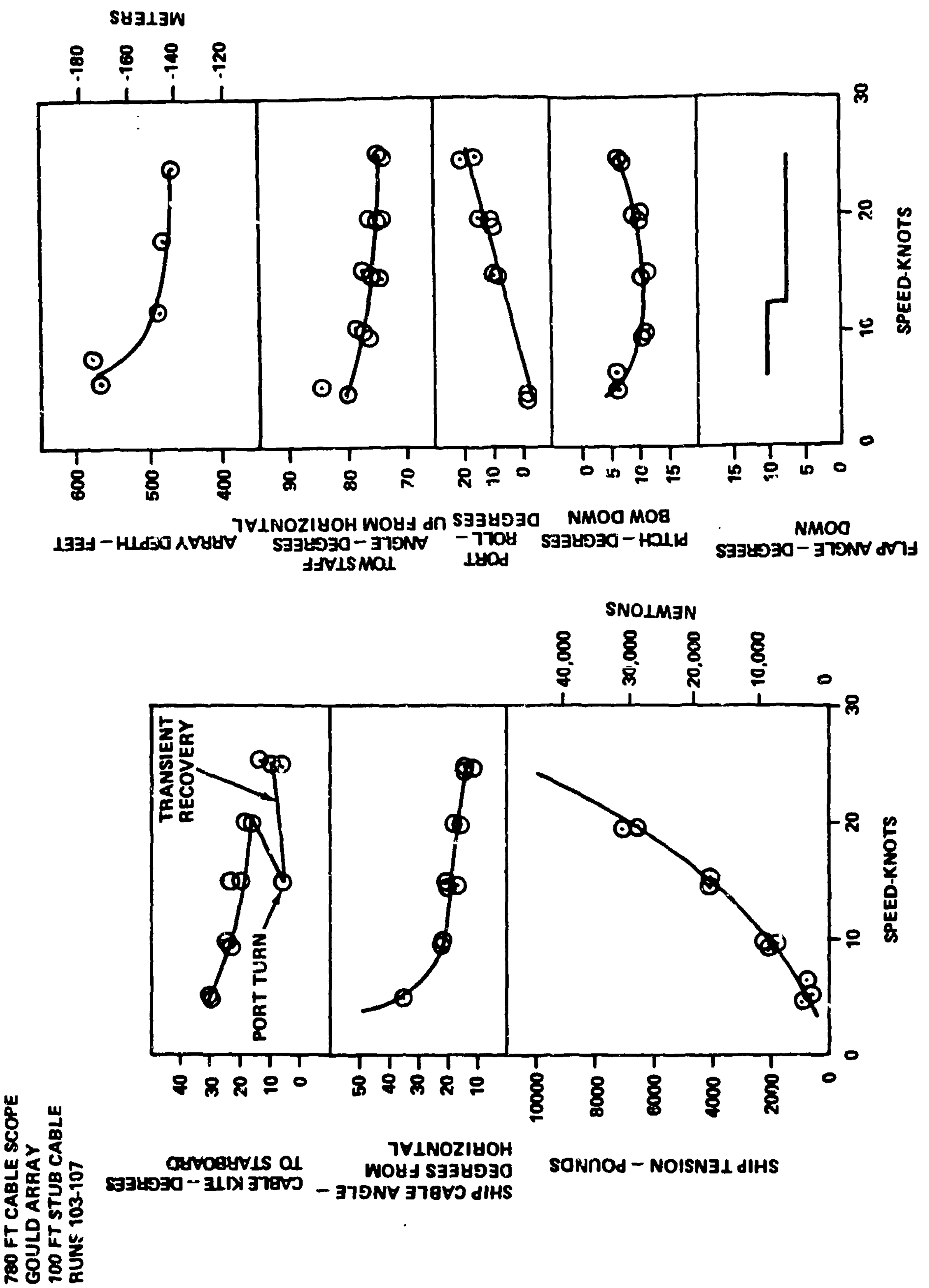


Figure 18. R/V Athena Runs 103-107

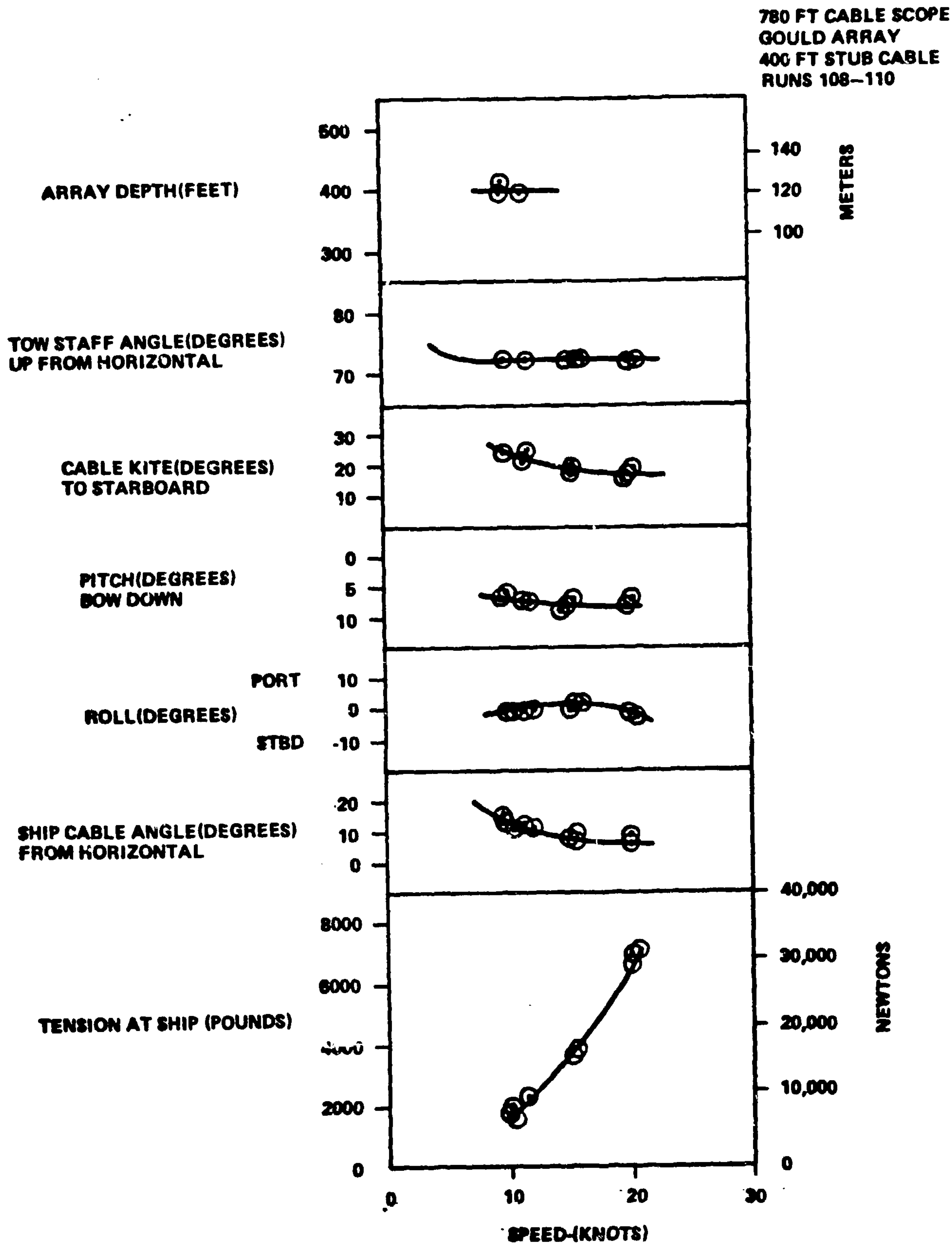


Figure 19. R/V ATHENA RUNS 108-110

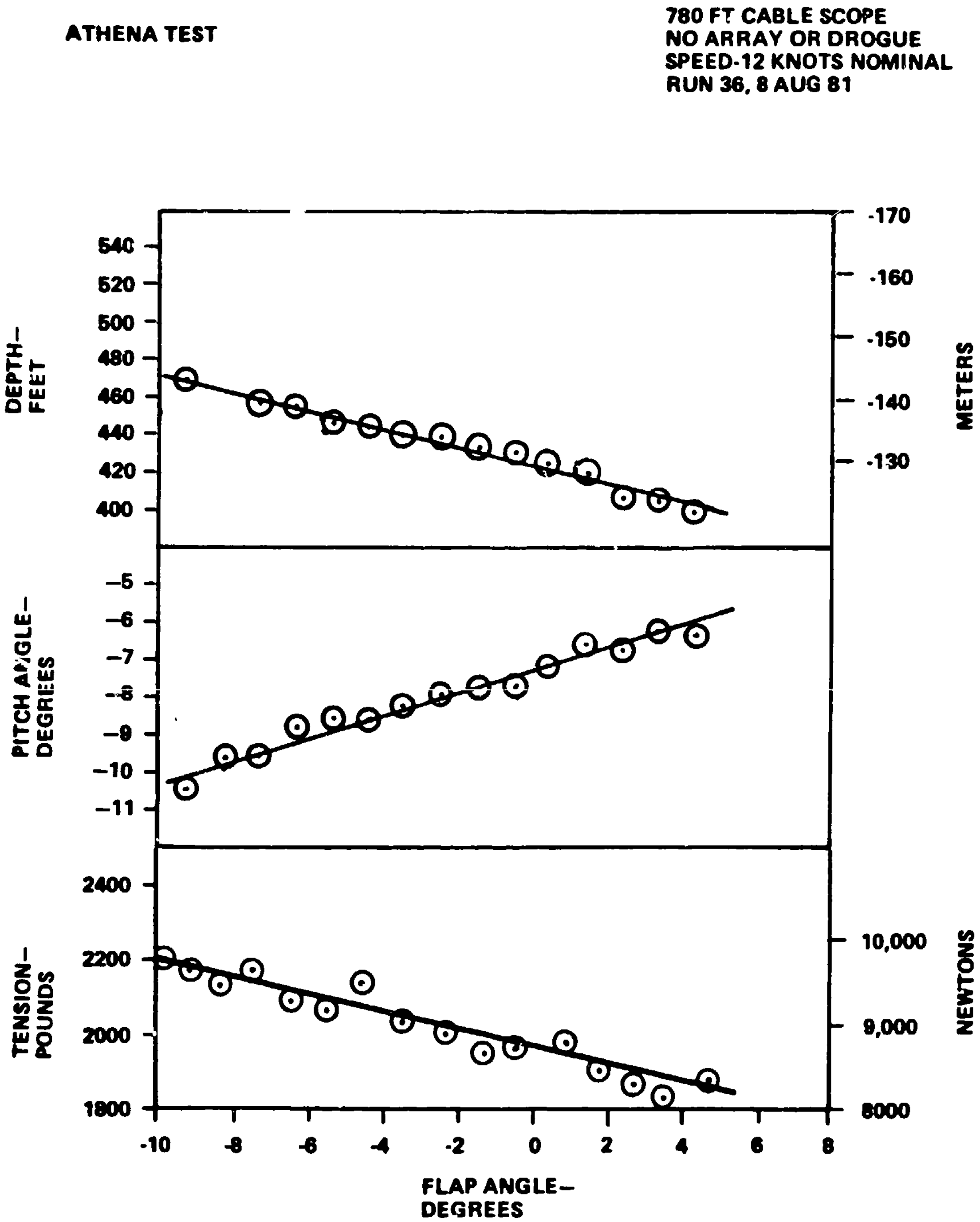


Figure 20. R/V ATHENA Run 36 - Flap Adjustment at 12 Knots

4. CONCLUSIONS

Based on the model basin tests of the half scale and full scale depressor models and the at-sea evaluation aboard the R/V ATHENA the following are concluded:

1) The depressor meets the near term goal of developing 7000 pounds (31.1 kN) depressing force while towing an array which generates 1980 pounds (8.8 kN) of drag at 35 knots.

2) Essentially the depressor meets the long term goal of 45 knots without actually demonstrating 11,500 pounds (51.2 kN) of depressing force or 500 foot (11.52 m) depth. The long term goal was not demonstrated due to existing tow cable strength and drag limitations, and ship speed.

3) The depressor provides a stable tow configuration up to speeds of at least 35 knots with and without an array.

4) The depressor provides the capability of remotely controlling depth or roll from the tow ship without changing tow cable scope.

5) Tests aboard the R/V ATHENA demonstrated the ease of handling the lightweight, feed through concept depressor.

6) The depressor is suitable for continued use in testing towed arrays although some refurbishment is desirable.

5. RECOMMENDATIONS

Based on the experience of the towing basin and at-sea demonstrations and tests reported herein the following recommendations are offered:

1. High speed, low drag tow cable development be continued.

2. Further analysis of the existing hydrodynamic data be made, particularly with respect to flap effectiveness.

3. The existing full scale depressor be refurbished, the tow staff tension sensor circuit improved and the depth sensor calibrated vs. speed in the model basin for further use as a research tool.

4. A better fit of Flexnose fairings to the tow cable be provided if the same tow cable is to be used again.

5. After the mode is refurbished demonstrate high speed capabilities and obtain additional high speed data.

6. Analyze acoustic data obtained during sea-trial 1A6 to determine affect (if any) of depressor on self noise of array.

ACKNOWLEDGMENT

The author gratefully acknowledges Captain Arthur Gilmore and LTCR Charles Farrell (ONR) for their continued support of high speed towed systems; Dr. P. Rispin of DWTNSRDC for his technical guidance and assistance; and Mr. Stan Rupinski of NUSC/NLL for sharing his experience in depressor tow system design and testing.

APPENDIX A

DRAWING LIST - FULL SCALE DEPRESSOR

Drawing No.	Revision	ACN	Sheets	Title
100403	D	E	1	Wing Depressor
105439	B	A	1	P/L Depressor Body Electronics
105441	A	B-D	1	Coupling - Array
105442	D	E,F	1	Tube - Aft
105443	A	B-F	1	Aft Bulkhead
105444		A,B	2	Tow Point
105445		A-D	1	Shell, Upper
105446		A-C	1	Flap (Tail Fin)
105447		A	1	Pin, Flap
105448		A,B	1	Tail Fin - Detail & Instl.
105449		A,B	1	Plate - Mounting Electronics
105451			1	Pivot Pin
105452		A	1	Towstaff Arm
105453	B		1	Pivot Tow Staff
105454			1	Cover
105455		A	1	Pendulum Assy.
105457		A	1	Retainer Pendulum
105458			2	Nose
105460			1	Tow Cable Assy.
105461		A	1	Sleeve Bearing
105462			1	Long, Bulkhead
105463			1	Pivot Tube
105464			1	Pivot Tube Gusset
105467		A,B	1	Guide Ring
105468	A	B,C	5	Stuffing Tube Tow Cable
105469			4	Stuffing Tube Instrument Cable
105470			1	Tow Point Tube
105471			1	Spanner
105472			1	Push Rod
105473			1	Adjuster Screw
105474			1	Yoke

APPENDIX A (Cont'd)

Drawing No.	Revision	ACN	Sheets	Title
105475			1	Pivot Yoke
105476			1	Shift Gear
105477			1	Shaft Worm
105478	A		1	Gear
105480		A	1	Gear Box Assy.
105481		A	1	Shaft Assy.
105482		A-C	1	Gear Idler
105483		A	1	Key
105484			1	Hinge Pin - Lower Flap
105485			1	Shaft - Yoke
105486			1	Shift Arm Assy.
105487			1	Yoke - Gear
105488	A	B,C	1	Plate Mounting Pendulum Pitch
105489		A	1	Post
105490		A	1	End Plug
105492		A	1	Pin Target
105493		A,B	1	Standoff
105494		A,B	1	Gear Motor
105495			1	Worm Wheel Sector
105497			1	Shaft Shifter
105498		A	1	Shift Lever
105499		A	1	Shaft - Worm Wheel
105501			1	Electronic Assy.
105502		A-D	1	Gear Box
105503			1	Pin Shifter
105504			1	Circuit Card Assy.
105505			4	Printed Wiring Board
105506			1	Depressor Body Schematic Diagram
105509	A		1	Keeper Plate
105510	A		1	Washer
105511			1	Spacer

APPENDIX A (Cont'd)

Drawing No.	Revision	ACN	Sheets	Title
105513			1	Vacuum Test Fitting
105514			1	Pressure Sensor Plug
105515			1	Stuffing Tube Washer
105516			1	Nose Counter Weights
105517			1	Depressor Internal Arrangements